GEOPHYSICAL INVESTIGATIONS

Naval Submarine Base - New London

Groton, Connecticut

Prepared for

ATLANTIC ENVIRONMENTAL SERVICES, INC.

October 1990

Weston Geophysical
CORPORATION

October 2, 1990

Mr. Curt Kraemer
Atlantic Environmental Services, Inc.
188 Norwich Avenue
Colchester, CT 06415

Subject: Geophysical Investigations
Naval Submarine Base – New London
Groton, Connecticut

Dear Mr. Kraemer:

In accordance with your authorization, Weston Geophysical has completed geophysical surveying to assist Atlantic Environmental's characterization of disposal areas at the New London Subase. This submission is a formal presentation of the investigative methods and results of our efforts.

We appreciate the opportunity to provide geophysical services and welcome any questions or comments regarding this report.

Sincerely,

WESTON GEOPHYSICAL CORPORATION

Mark Blackey dg.
Mark Blackey
Manager, Geophysical Services

MB:cc–3642J
WGC – 17996–03

Enclosure

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SECTION 1

EXECUTIVE SUMMARY

Geophysical surveying was accomplished at five areas of concern at the New London Subase (the Acid Pit Storage Area, a former gasoline station, the Area A Landfill, the DPDO Area, and the Goss Cove Landfill) to assist characterization of subsurface conditions at those areas. Ground penetrating radar (GPR), magnetometry, and electromagnetic (EM) terrain conductivity methods were employed during these surveys.

Key results include: 1) confirmation of a probable underground storage tank at the former gasoline station, 2) identification of probable salt contamination and landfill materials at Area A, 3) identification of numerous buried metal objects and extensive fill at the DPDO area, and 4) the limits of a landfill and numerous buried metal objects at the Goss Cove Landfill.

INTRODUCTION

Geophysical surveys were conducted at several locations throughout the New London Naval Submarine Base (Subase) to assist Atlantic Environmental Services with characterization of those sites. Areas of concern included the Acid Pit Storage Area, a former gasoline station site, the Area A Landfill, the DPDO area, and the Goss Cove Landfill. The objectives of the geophysical surveys entailed identification of buried, man-made features such as storage tanks or possibly drums, and delineation of contaminant plumes.

Field work was accomplished between June 13–15 and 25–27, 1990 by Weston Geophysical, with logistical support provided by Atlantic Environmental and civilian Subase personnel.

METHODS OF INVESTIGATION

Survey Control

Survey control was provided partly by a Atlantic Environmental subcontractor and partly by Weston Geophysical's field personnel. Licensed surveyors established reference grids at the former gasoline station, the Area A Landfill, the DPDO area, and the Goss Cove Landfill. Weston Geophysical used taped measurements referenced to the grids and cultural features (buildings, etc.) to locate specific geophysical measurement locations at all locations (except for the Acid Pit Storage Area, where no reference grid was available).

Magnetometry

Magnetometry surveying was performed at the Area A Landfill, DPDO area, and Goss Cove Landfill to identify buried ferrous metal objects. Data were acquired using a Geometrics model G-856 digital proton precession magnetometer at intervals of 10 feet along each survey traverse. Upon completion of surveying at each area, data were downloaded to a portable computer to facilitate processing and preparation of magnetic contour maps.

Additional information regarding magnetometry is provided in Appendix A.

Electromagnetic Terrain Conductivity

Conductivity profiling was accomplished at the Area A Landfill, DPDO Area, and Goss Cove Landfill to identify electrically conductive subsurface contamination and to confirm results of the magnetometry surveys. Electromagnetic (EM) conductivity data were obtained using a Geonics model EM-31 equipped with a digital datalogger. The datalogger enabled transferring EM data to a portable computer for contouring.

Appendix B provides background information regarding electromagnetic terrain conductivity methods.

Ground Penetrating Radar

Ground penetrating radar (GPR) data were obtained at all sites to identify stratigraphy or subsurface objects such as storage tanks. GPR data were acquired using GSSI model SIR–8 instrumentation coupled with a 500 megahertz antenna and a graphic recorder. Hardcopy printouts produced by the graphic recorder were analyzed for stratgraphic information as well as evidence of trenches, backfill material, or buried objects.

Additional information concerning GPR profiling is provided in Appendix C.

SECTION 2

RESULTS

Acid Pit Storage Area

GPR data were acquired along traverses shown on Figure 2 to identify a suspected underground tank. Subsequent to the geophysical field survey, the actual location of the tank was identified (in an area outside of the geophysical coverage) by Atlantic Environmental.

Locations of small buried objects ("point targets") disclosed by GPR data at this area are also shown on Figure 2. These point targets are generally indicative of either pipes or cobbles, not large structures such as storage tanks. The largest possible subsurface object identified at this area could be either a large pipe or cobble, or a very small tank. That feature is located near Line 0+30N, Station 0+32E as shown on Figure 3.

Former Gasoline Station

GPR data were acquired at the former location of a gasoline station. This area is currently located beneath a roadway on the southwest side of Building 164; a plan map of GPR traverses from this area is provided as Figure 4. The "survey grid points" shown on Figure 4 were placed by others; GPR traverses were referenced to those grid points by taped measurements.

Numerous point targets were noted on GPR recordings from this area, indicating either many pipes/conduits or boulders. One anomaly indicative of a tank at the bottom of an excavation was observed at Line 1–10, 20 feet east of Line C (see Figures 3 and 4). Near this location, GPR reflectors possibly indicative of backfilling were noted (identified as "disturbed soils" on Figure 4). The general area of disturbed soils fits the suspected location of three suspected underground storage tanks shown on a map provided by Atlantic Environmental. Based on the GPR results alone, it appears that only one of the tanks in currently still in the ground (location described above). We recommend confirming this interpretation by means of test pits at the locations of both the inferred tank and the disturbed soils.

Area A Landfill

A combination of GPR, magnetometry, and EM terrain conductivity were accomplished at the Area A Landfill. Plan maps showing the GPR traverses are shown on Figure 5; magnetometry and EM conductivity coverage are presented on Figure 6.

GPR Results

GPR data collection at Area A was limited to locations where the GPR antenna could access the ground surface. Regions excluded from the GPR survey include the sandbag storage piles and locations cluttered with surface metal objects.

Most GPR data from Area A is characterized by numerous mottled reflectors commonly indicative of fill materials. The appearance of these reflectors is similar to the "backfilled excavation" noted on an example GPR recording shown on Figure 3. A particularly thick section of these mottled reflectors is located near Line D at Station 11; this possible landfilled zone thins gradually towards station 13.5 (i.e., thins towards the east).

Numerous areas of limited GPR penetration were noted, as shown on Figure 5. Many of these areas exhibited salt staining; others were coincident with the roadway leading west out of the Area A Landfill. Because the GPR method cannot penetrate salty (electrically conductive) soils, direct investigations (test pits, etc.) may be warranted to characterize subsurface conditions at these areas.

Limited areas of "ringing" (reverberating GPR signals) were observed, as also shown on Figure 5. This ringing is typically associated with shallow buried metallic objects; test pits are suggested for these locations to characterize the anomaly sources.

Continuous GPR reflectors noted near Lines 40 through 46 may represent the bottom of relatively clean fill (loam?) which appears to be underlain by landfill materials. The thickest sections of the inferred "clean" fill is near Line C.5, Station 46.5 and Line 45.5, Station D.5.

Numerous individual objects were noted on the GPR recordings; their locations are shown on Figure 5. Two objects are particularly large and may warrant direct investigation by test pits. They are located near Line E, Station 25.9 (approximately 5 feet deep) and Line 33, Station B.8 (approximately 7 to 8 feet deep).

Magnetic and EM Conductivity Results

Magnetic and EM Conductivity data are presented as contour maps on Figures 7 through 10.

Figure 7 is a magnetic contour map from the west end of Area A. The region west of Line 13.5 exhibits little magnetic variation, indicating that no significant ferrous objects are buried there. This region is therefore likely to be outside the disposal limits.

Buried metal objects may be located east of Line 13.5, as indicated by numerous magnetic variations. Locations of suggested test pits, intended to investigate the most significant magnetic anomalies, are shown on Figure 7 and are listed below in decreasing order of priority: 1) 20 feet south of survey point 17C, 2) 5 feet north of survey point 15D, 3) at Line 13.5, 10 feet south of Station C, and 4) 25 feet south of survey point 18B. Additional test pit locations could be suggested, but the specific locations listed above are likely to be representative of subsurface conditions.

An EM conductivity contour map from the west end of Area A is provided as Figure 8. This map indicates a lack of conductivity anomalies at the northwest corner of the survey area, similar to the magnetic contour map (Figure 7) discussed above. High conductivity values (up to approximately 300 mmhos/m) in the eastern portion of the survey area may be due to either salt or landfilled materials. Two test pits are suggested based on the EM contour map alone; their locations are shown on Figure 8. The first test pit (Line 13.5, 10 feet south of Station C) is coincident with a test pit shown on the magnetic contour map. The second test pit, at survey point 16C, is intended to identify the source of the highest conductivity values noted during this survey.

Figure 9 presents magnetic and EM conductivity contour maps for a small region located east of the deployed parking area. Both maps show a northwest anomaly trend (most apparent on the EM conductivity map). A single test pit located 15 feet east of survey point 37E is recommended to identify the source of high conductivity values (greater than 120 mmhos/m) and possibly the magnetic anomaly.

An EM conductivity contour map for the easternmost portion of the Area A Landfill (adjacent to the Racquetball Center) is provided as Figure 10. Conductivity values throughout most of this survey area are not as high as observed in other portions of Area A (up to 80 mmhos/m), but could still represent limited landfilling. A single test pit at the area of highest observed conductivity values is suggested to characterize subsurface materials in that area.

DPDO Area

GPR, magnetometry, and EM conductivity data were obtained to characterize subsurface conditions at the DPDO area. Extensive surface metal (buildings, objects awaiting auction, utilities) were present at this site, thus limiting the applicability of EM and magnetic methods. Magnetic, EM conductivity, and GPR traverses and results are presented on Figures 11, 12, and 13.

Background magnetic values at the Groton, Connecticut area should be in the vicinity of 55,000 to 56,000 gammas. Values shown on the magnetic contour map (Figure 11) vary considerably from background even in areas relatively free of surface metal. Consequently, buried metal objects are likely throughout large portions of the DPDO area.

Examples of anomalous magnetic values likely to represent areas of buried ferrous metal objects include the region north of Line 17 (approximate coordinate 350N), particularly where magnetic values greater than 57,000 gammas are present.

Many of the EM conductivity anomalies shown on Figure 13 correspond to magnetic anomalies shown on Figure 11. For example, low conductivity values near coordinates 420N, 175E and high conductivity values near coordinates 425N, 50E are similar in appearance to magnetic anomalies. Both EM and magnetic data appear to be responding to the same metallic anomaly source in these locations.

High EM conductivities south of Building 355 appear to be related to either the building alone, or possibly to adjacent utilities.

GPR data from the DPDO area (Figure 13) exhibited zones of multiple reflectors commonly associated with backfill materials. Localized areas of limited GPR penetration are probably due to either road salt storage or other electrically conductive overburden conditions. Ringing of GPR signals noted on limited portions of Figure 13 may represent either shallow, buried objects or possibly reflections from large above-ground metal structures.

Test pit locations recommended on the basis of either the EM or magnetic data alone are shown on Figures 11 and 12. The test pits at coordinates 300N,00E (Figure 11), and 435N,50E and 550N,100E (Figure 12), are recommended as having the highest order of priority.

No test pits are recommended on the basis of the GPR data alone, because GPR results indicate fill materials throughout virtually the entire DPDO site.

Goss Cove Landfill

A combination of magnetometry, EM conductivity, and GPR data were acquired at the Goss Cove Landfill (outside the Nautilus Museum) to identify the extent of the suspected landfill and to confirm, if possible, the specific locations of buried metal objects. Because the survey area is within the Nautilus Museum's parking lot, work was accomplished during periods of time when the museum was closed.

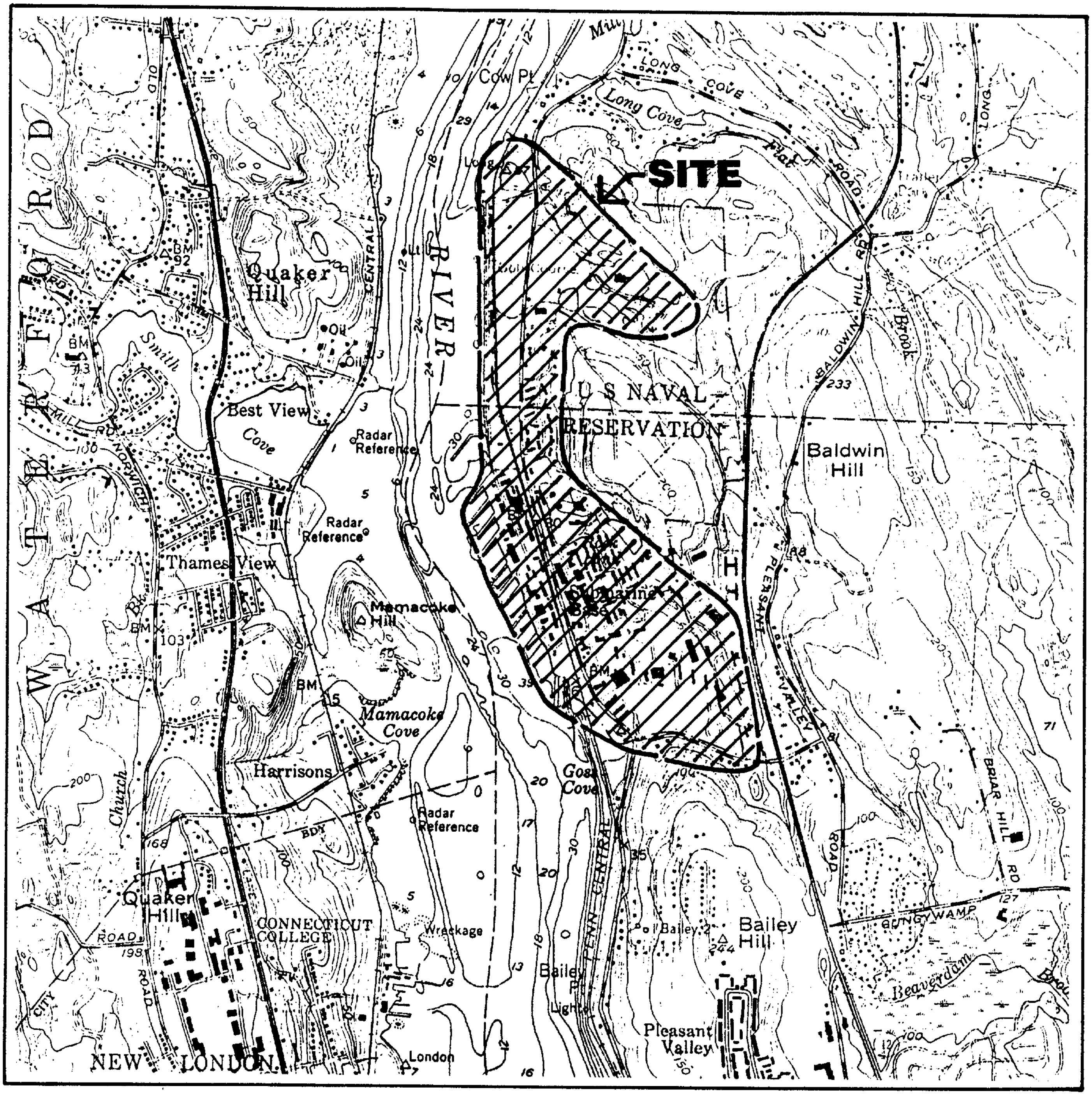
Figure 14 presents a magnetic contour map prepared from data acquired along north-south traverses. Many anomalies (tightly grouped magnetic contours) are evident, particularly south/southwest of the line labeled as "possible landfill boundary". That boundary was inferred from the magnetic and EM conductivity contour maps.

EM conductivity data were acquired along both north–south and east–west oriented traverses (Figures 15 and 16, respectively). On both figures, the interpreted landfill is represented by conductivity values less than zero or greater than 20 mmhos/m. Note that areas northeast of the "possible landfill boundary" exhibit little conductivity (or magnetic) variations; values on the south/southwest side of the inferred boundary range up to approximately 200 mmhos/m.

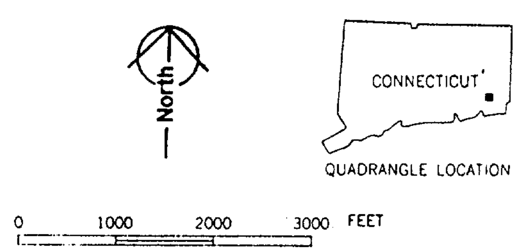
GPR data (Figure 17) were acquired in anomalous regions noted during the magnetic and EM surveys, and in areas where the magnetic or conductivity data could not be acquired due to surface metal objects. All of the traverses completed during the GPR survey exhibit reflectors characteristic of landfills, with only occasional areas where GPR penetration depth was limited (by electrically conductive materials near ground surface) or where possibly "clean" fill overlays other backfill materials.

Several suggested test pit locations are shown superimposed on the data from which the suggested locations were derived (Figures 14 through 17). Some test pits are based on more than one data set. Suggested test pits which are most strongly recommended are as follows: 1) 10 feet southeast of point B15, 2) 25 feet east of point D12, and 3) 15 feet southwest of point B19.

FIGURES



Basemap: U.S.G.S. 7.5 Minute Series (Topographic)
Uncasville, CT Quadrangle.



prepared by MB	Geophysical Investigation Naval Submarine Base - New London Groton, Connecticut	Area of Investigation	
checked by	Prepared for		
reviewed by	Atlantic Environmental Services, Inc.	Weston Geophysical	Fig. 1

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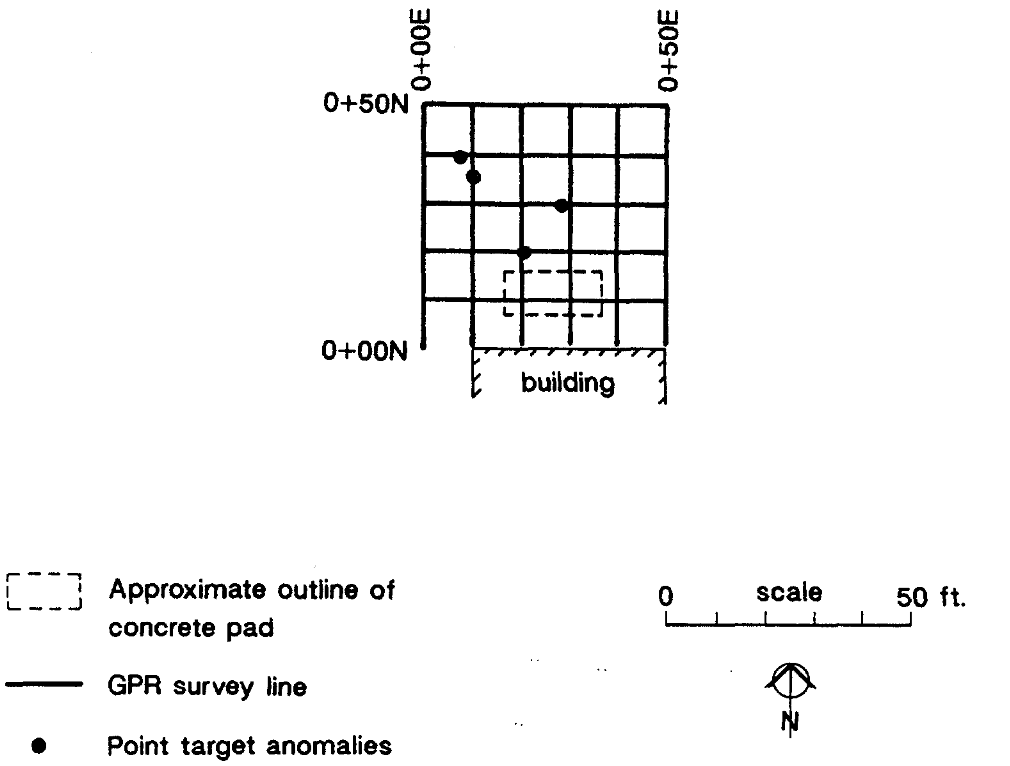

prepared by PG	Geophysical Investigation Naval Submarine Base - New London Groton, Connecticut	**Plan Map with GPR Anomalies** **Acid Pit Storage Area**	
checked by MB			
reviewed by [signature]	Prepared for Atlantic Environmental Services, Inc.	Weston Geophysical	Fig. **2**

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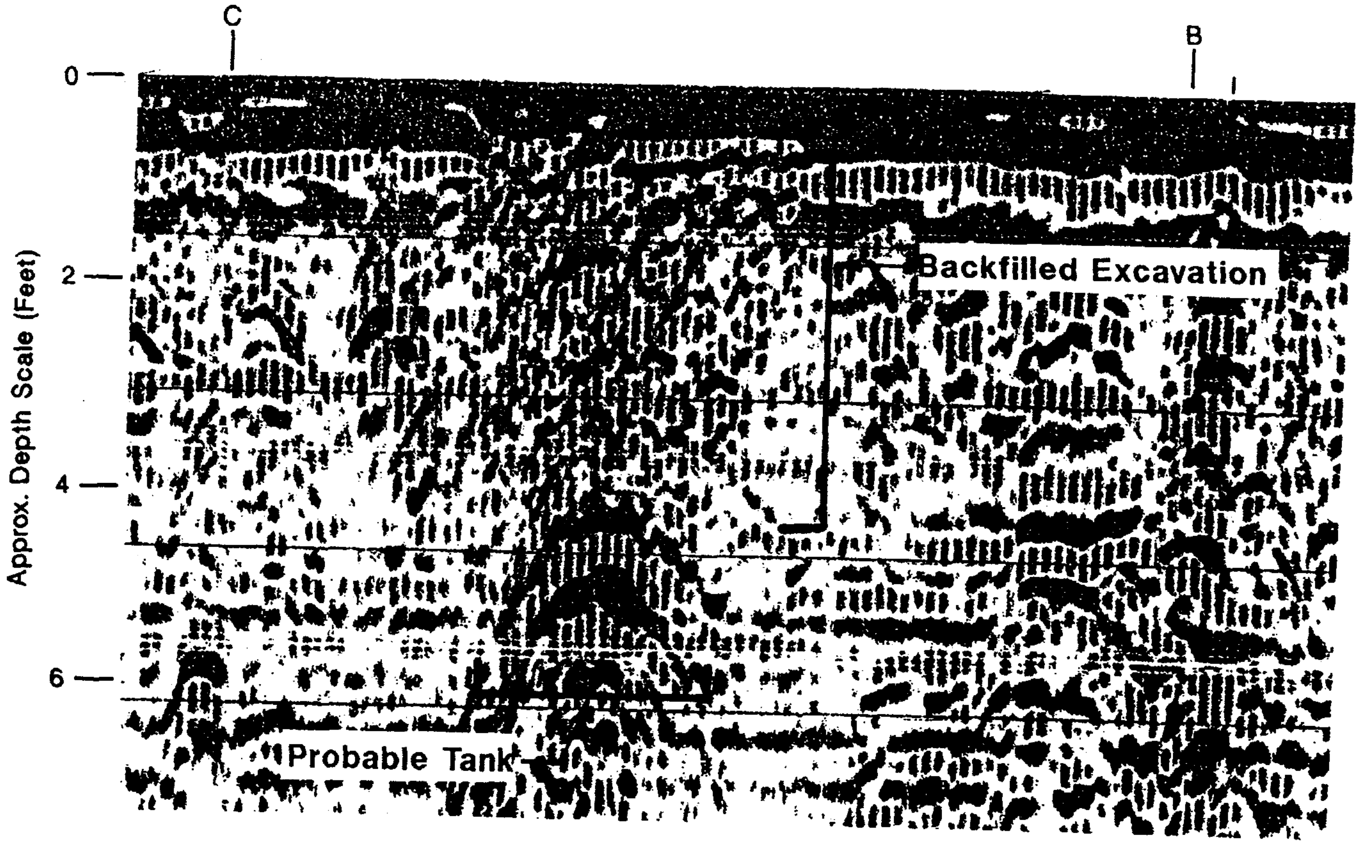
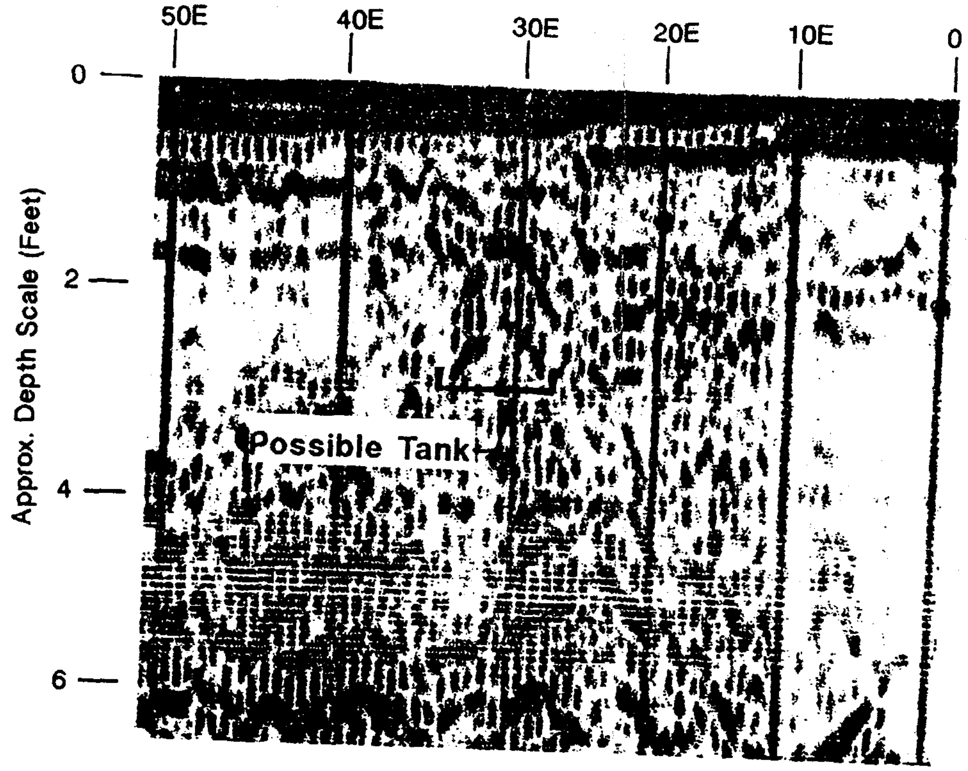
Probable Buried Tank
Former Gasoline Station

Line 1-10



Possible Buried Tank
Acid Pit Storage Area

Line 0+30N



prepared by MR checked by reviewed by	Geophysical Investigation Naval Submarine Base - New London Groton, Connecticut Prepared for Atlantic Environmental Services, Inc.	Example GPR Recordings Former Gasoline Station and Acid Pit Storage Area Weston Geophysical Fig. 3

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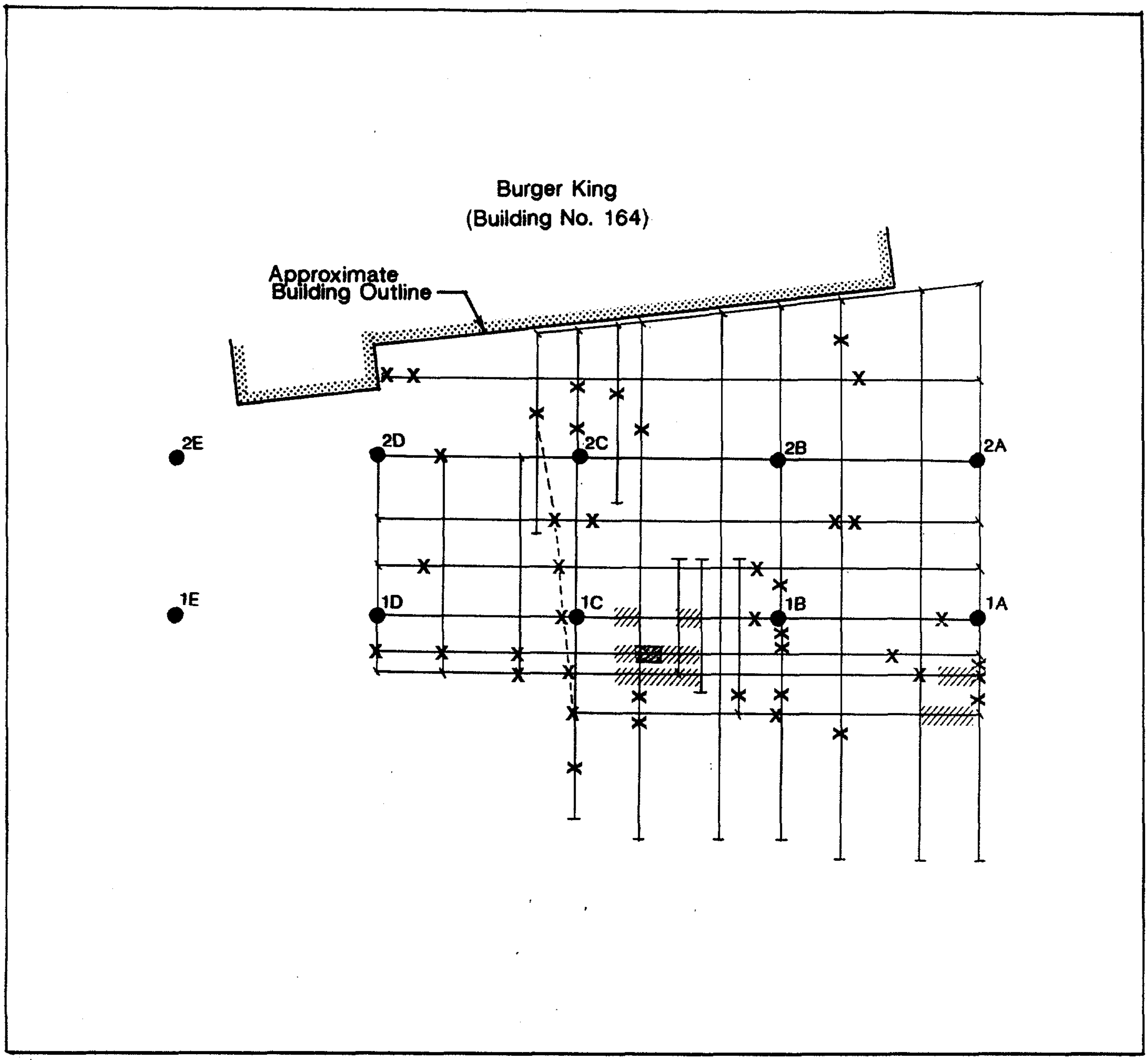


EXPLANATION

Ground Penetrating Radar (GPR) Coverage

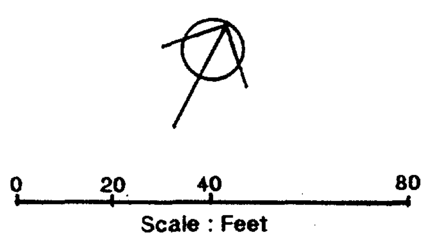
1A Survey Grid Point

Areas of Disturbed Soils (Backfilling ?)

Large Buried Object

X Point Target (Pipes, Conduits, & Boulders)

----- Possible Pipes or Conduits



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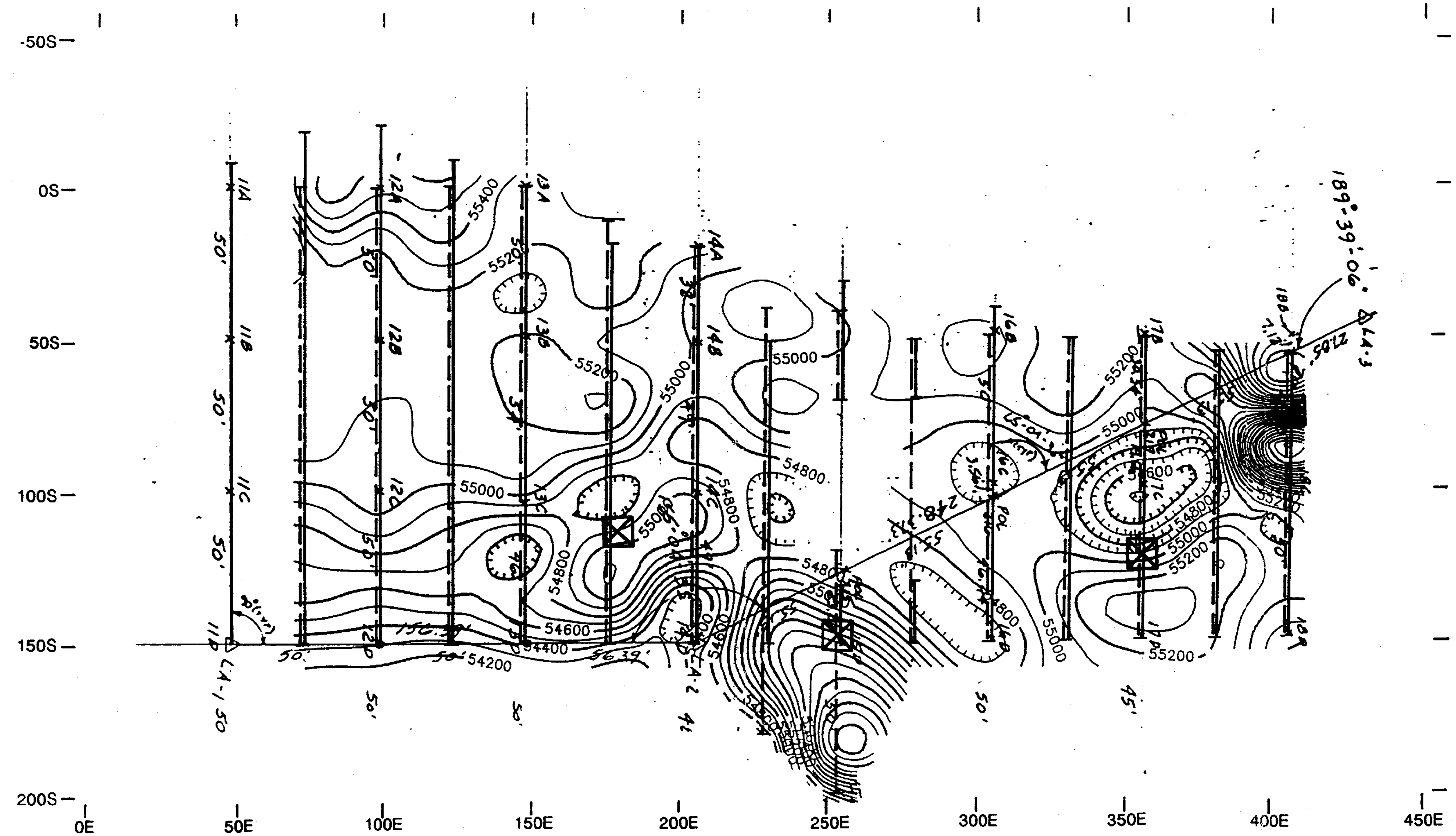

EXPLANATION

55000 — MAGNETIC CONTOUR, CONTOUR INTERVAL 100 GAMMAS

MAGNETOMETER SURVEY LINE

EM-31 SURVEY LINE

SUGGESTED TEST PIT LOCATION (BASED ON MAGNETIC DATA ALONE)

APPROX. NORTH

0 25 50 100

SCALE IN FEET

prepared by MB	Geophysical Investigation Naval Submarine Base - New London Groton, Connecticut Prepared for Atlantic Environmental Services, Inc.	Magnetic Contour Map West End of Area A Landfill
checked by		Weston Geophysical — Fig. 7
reviewed by		

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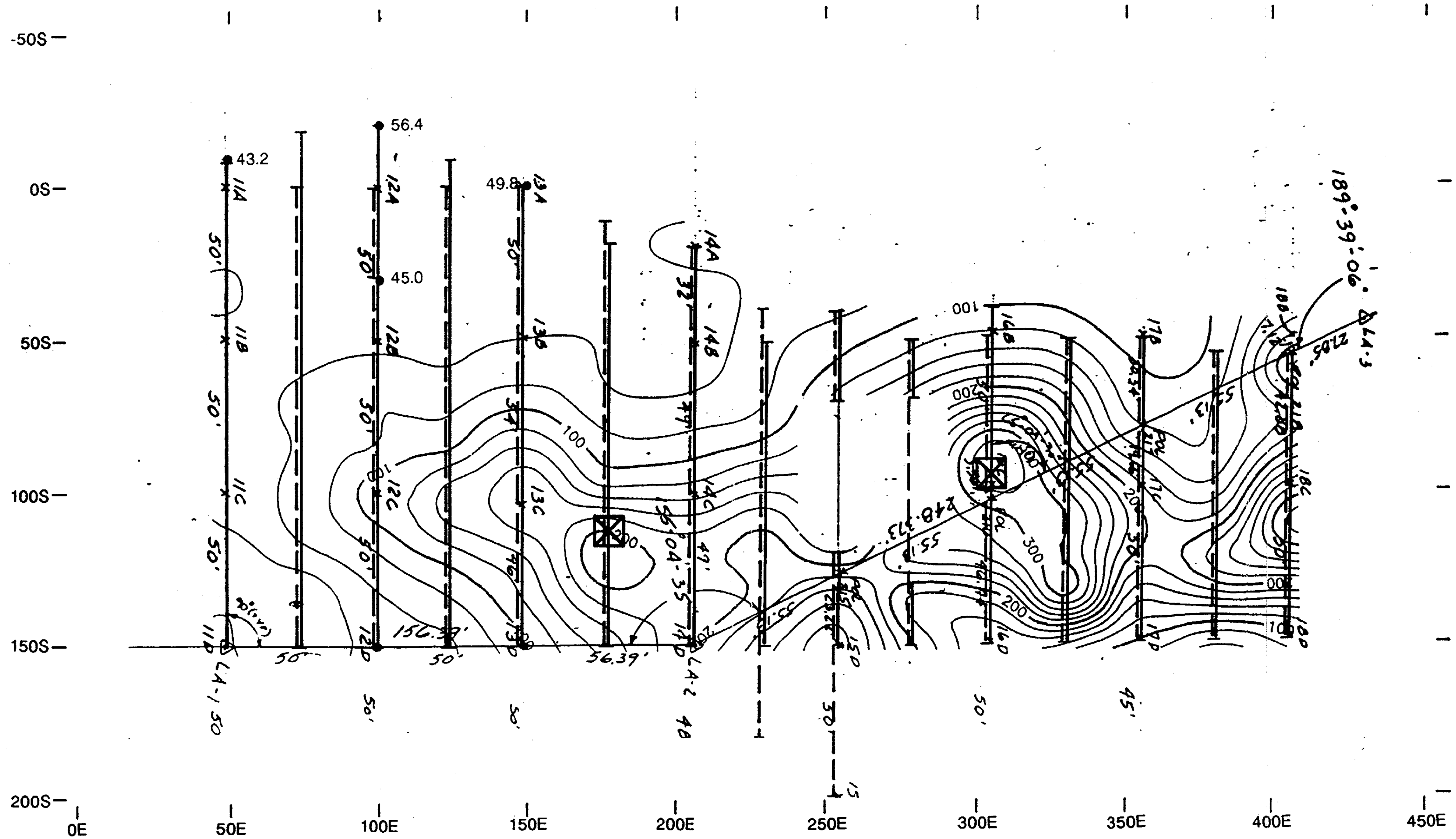

EXPLANATION

100 CONDUCTIVITY CONTOUR
CONTOUR INTERVAL: 20 MILLIMHOS/METER

SPOT CONDUCTIVITY VALUE

MAGNETOMETER SURVEY LINE

EM-31 SURVEY LINE

SUGGESTED TEST PIT LOCATION (BASED ON EM DATA ALONE)

APPROX. NORTH

0 25 50 100
SCALE IN FEET

prepared by MB	Geophysical Investigation Naval Submarine Base - New London Groton, Connecticut Prepared for Atlantic Environmental Services, Inc.	EM Conductivity Contour Map West End of Area A Landfill
checked by		Weston Geophysical — Fig. 8
reviewed by		10/90

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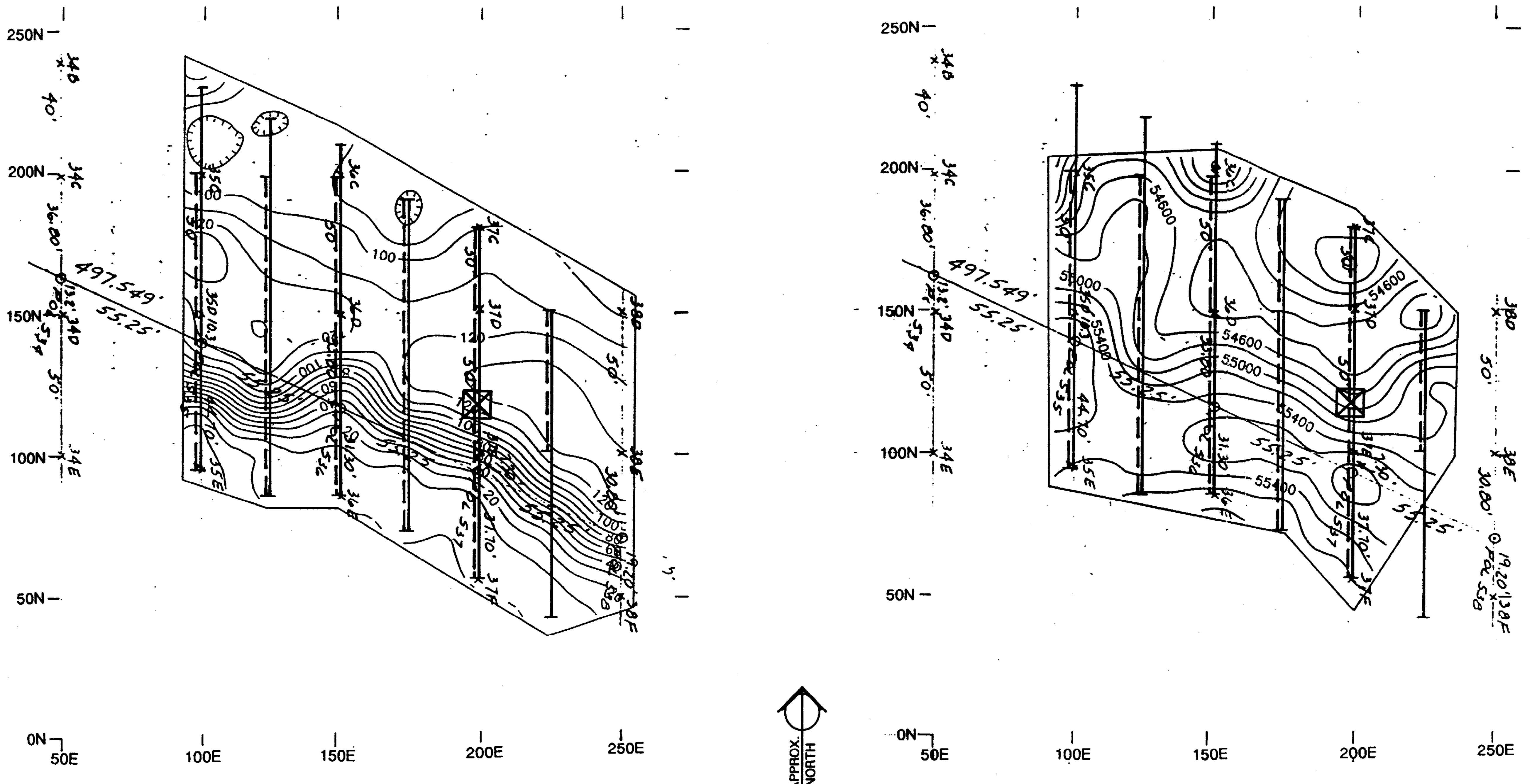

EXPLANATION

120 — EM CONDUCTIVITY CONTOUR (EM-31)
CONTOUR INTERVAL: 10 MILLIMHOS/METER

MAGNETOMETER SURVEY LINE

EM-31 SURVEY LINE

SUGGESTED TEST PIT LOCATION

0 25 50 100
SCALE IN FEET

EXPLANATION

55000 — MAGNETIC CONTOURS
CONTOUR INTERVAL: 200 GAMMAS

prepared by PG checked by MJS reviewed by	Geophysical Investigation Naval Submarine Base - New London Groton, Connecticut Prepared for Atlantic Environmental Services, Inc.	**Magnetic and EM Conductivity Contour Maps, East of Deployed Parking at Area A Landfill** Weston Geophysical — Fig. 9

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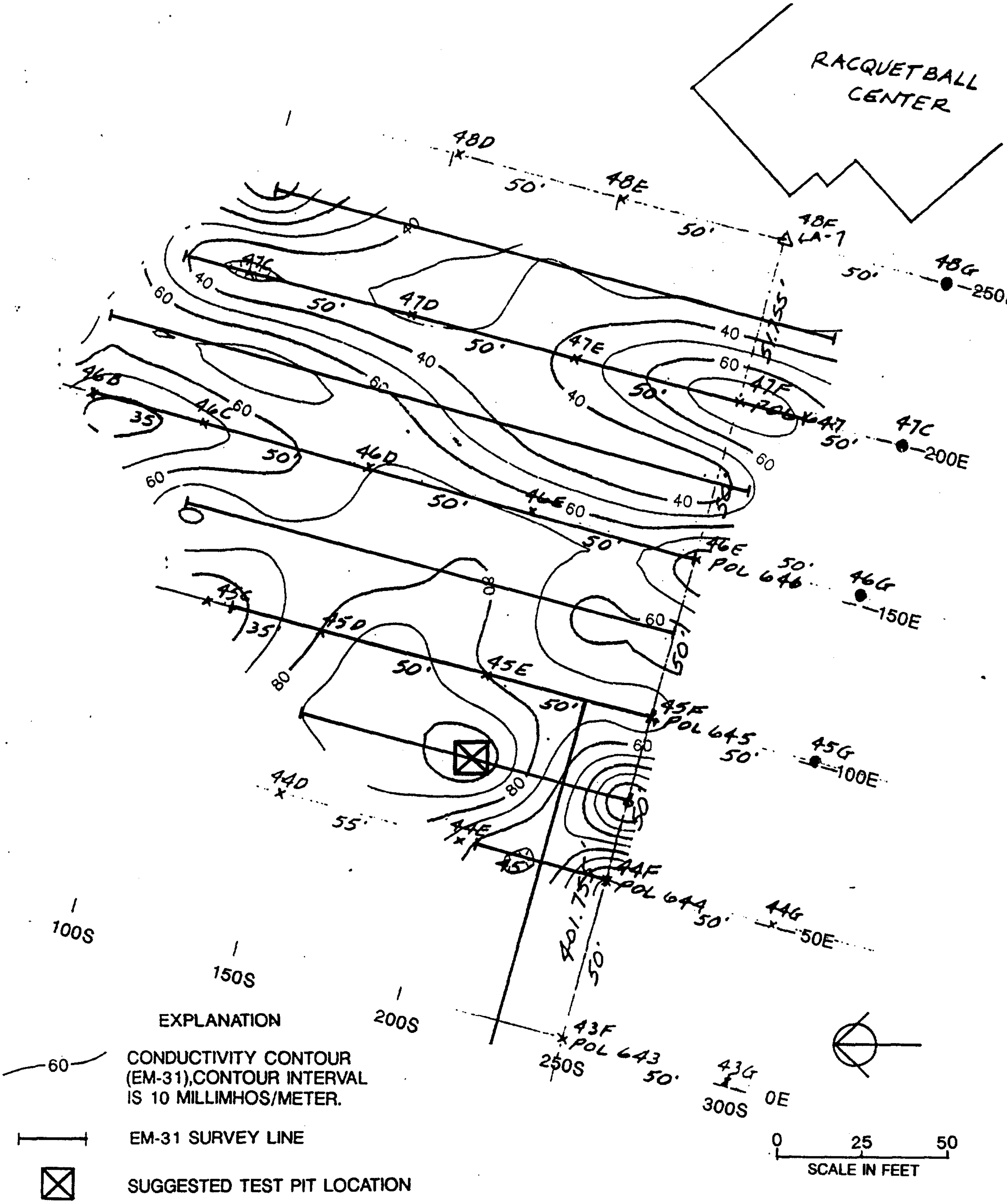

prepared by MB checked by [signature] reviewed by [signature]	Geophysical Investigation Naval Submarine Base - New London Groton, Connecticut Prepared for Atlantic Environmental Services, Inc.	EM Conductivity Contour Map East End of Area A Landfill Weston Geophysical — Fig. 10

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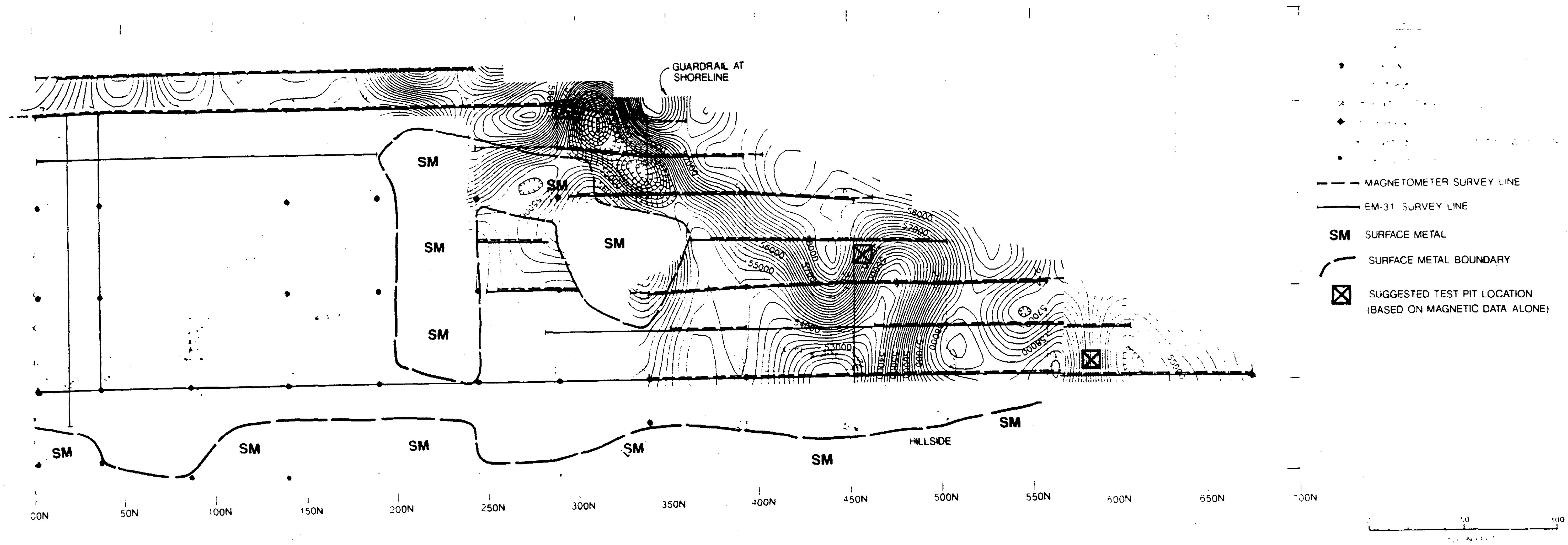

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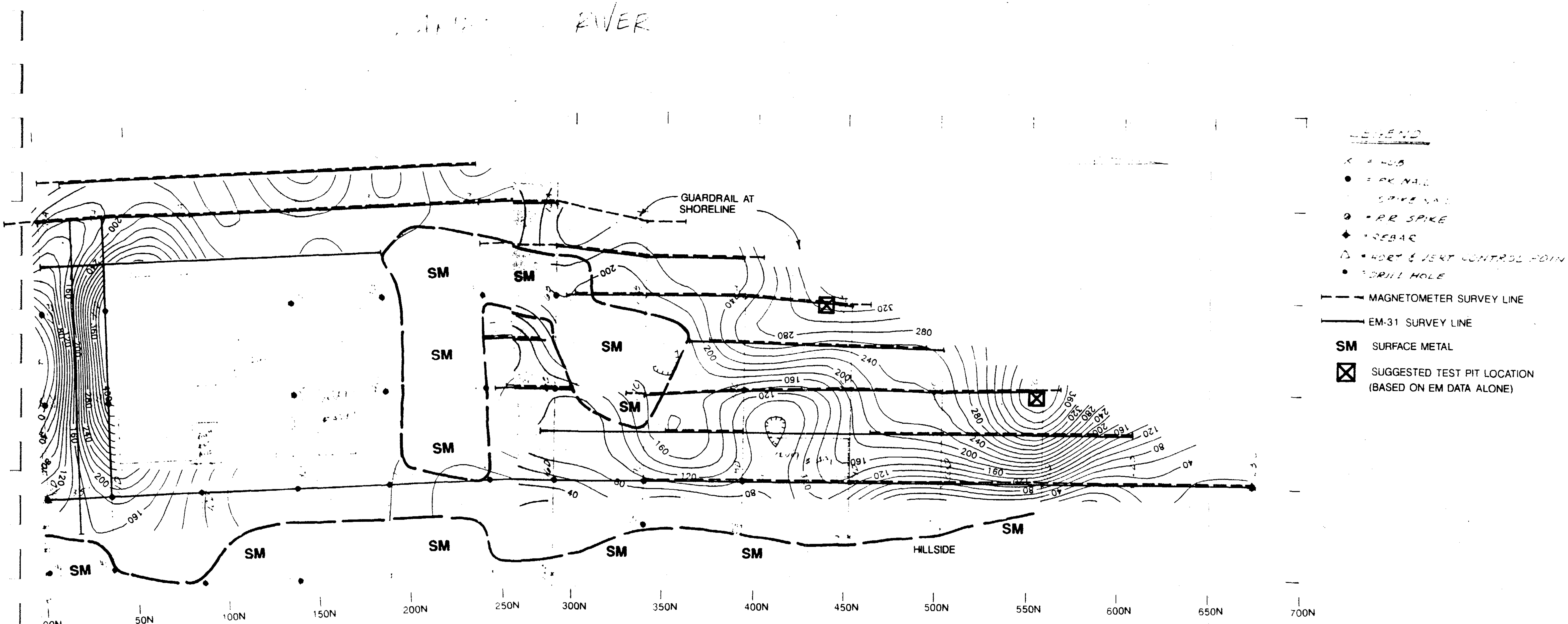

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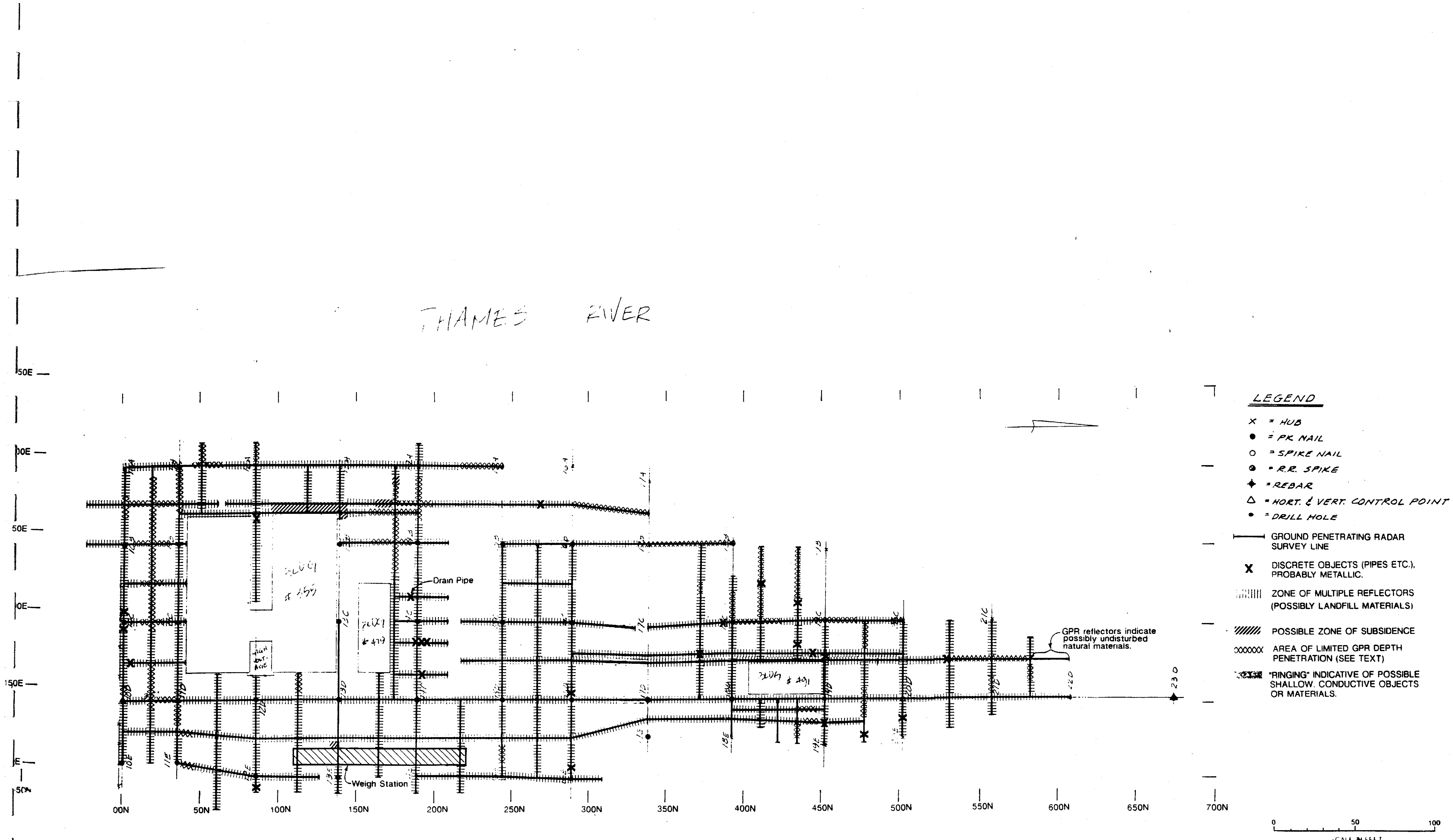

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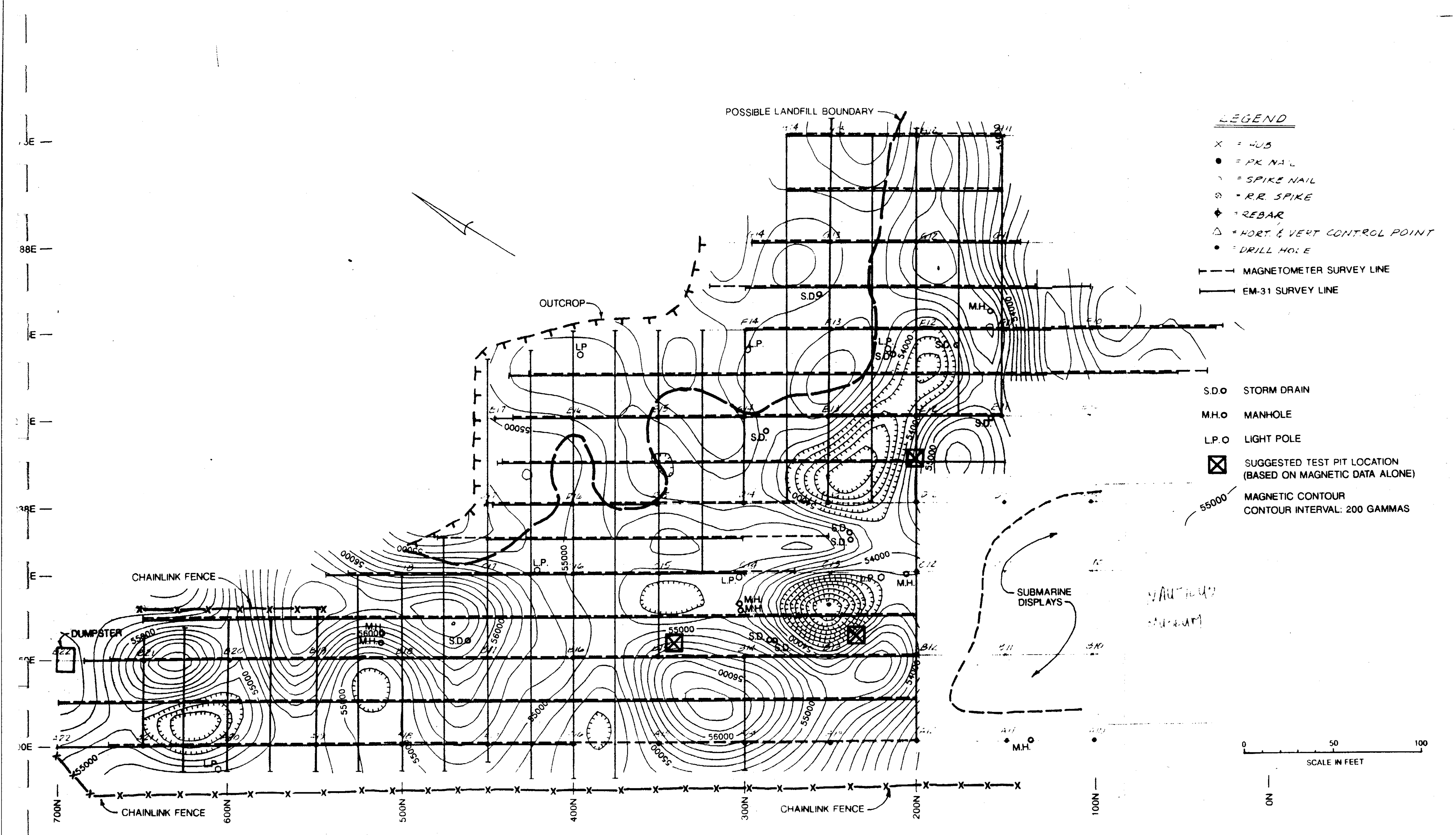

prepared by MB	Geophysical Investigation Naval Submarine Base - New London Groton, Connecticut Prepared for Atlantic Environmental Services, Inc.	Magnetic Contour Map Goss Cove Area
checked by		Weston Geophysical — Fig. 14
reviewed by		

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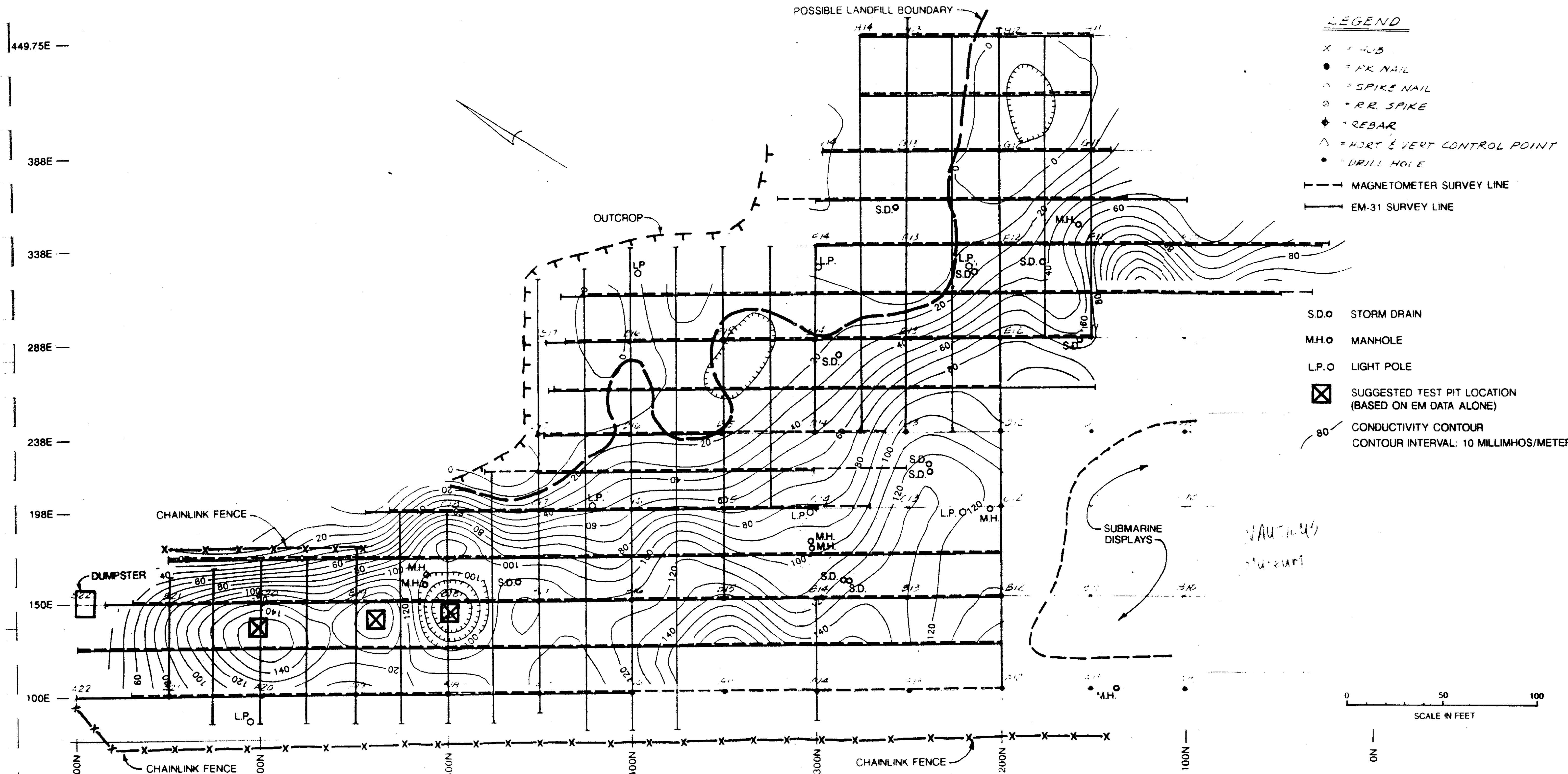

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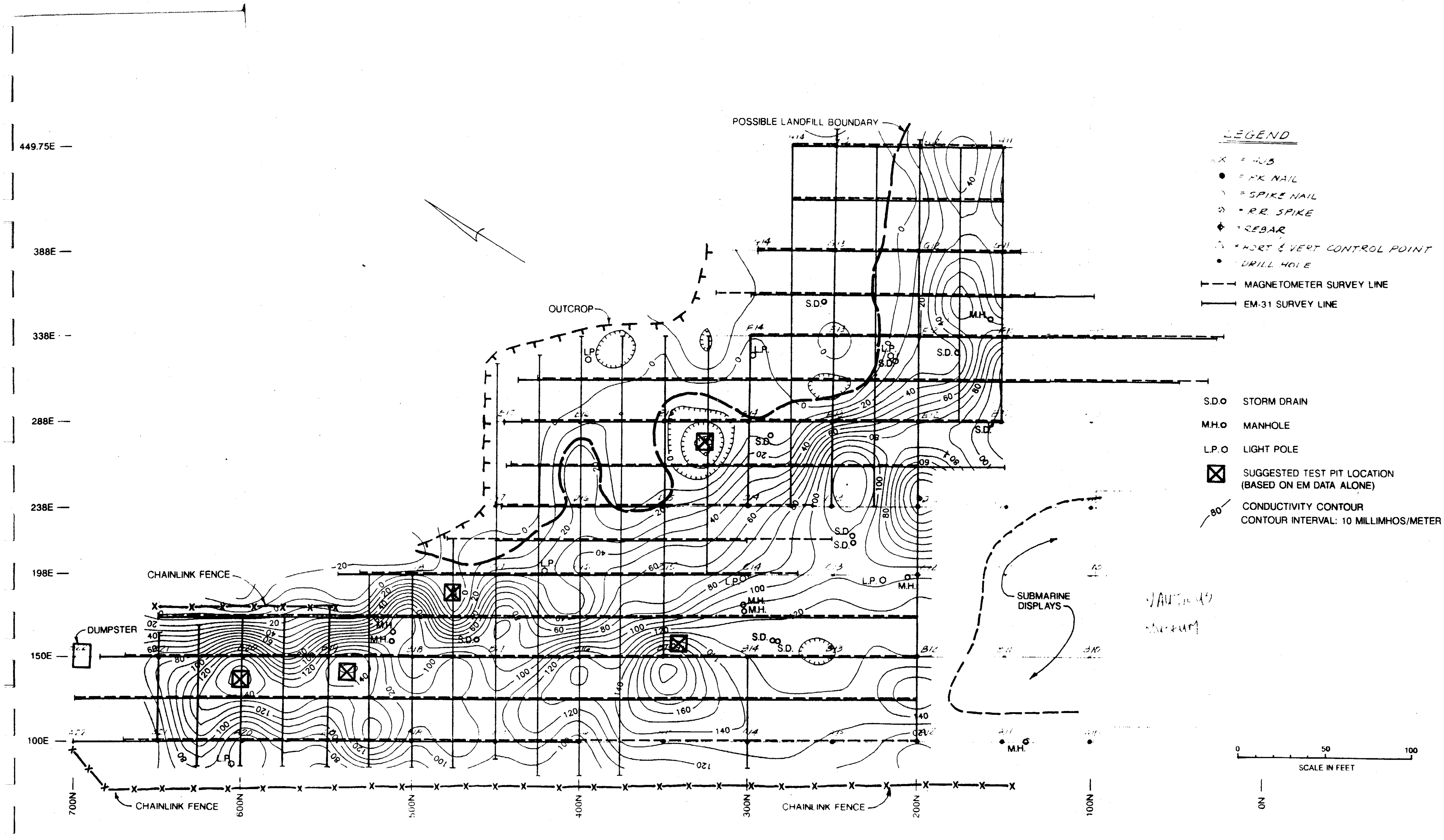

prepared by MR checked by reviewed by	Geophysical Investigation Naval Submarine Base - New London Groton, Connecticut Prepared for Atlantic Environmental Services, Inc.	EM Conductivity Contour Map (East-West Traverses) Goss Cove Area Weston Geophysical — Fig. 16

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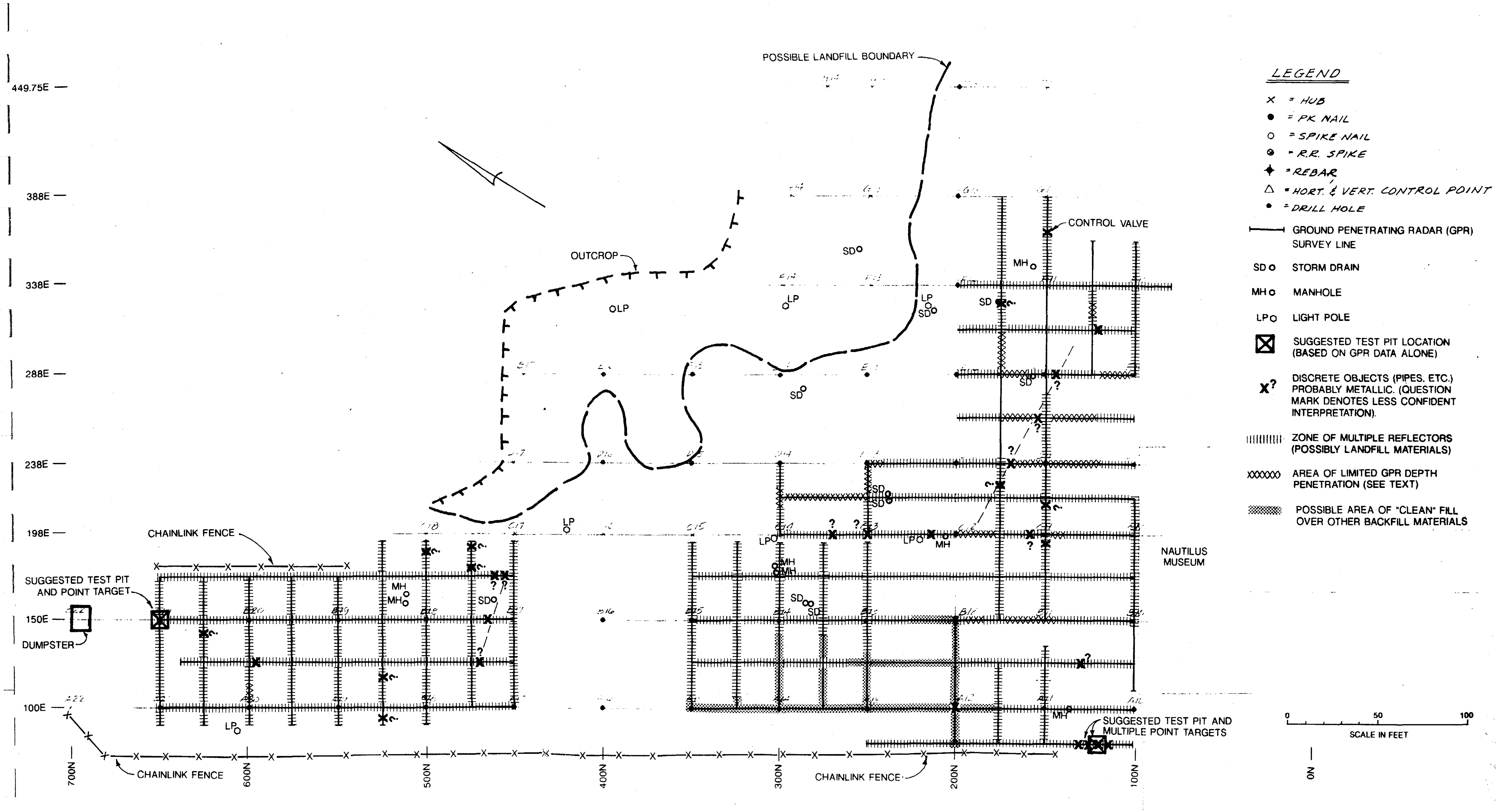

prepared by MB	Geophysical Investigation Naval Submarine Base - New London Groton, Connecticut Prepared for Atlantic Environmental Services, Inc.	GPR Anomaly Map Goss Cove Area
checked by		Weston Geophysical — Fig. 17
reviewed by		10/90

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APPENDIX A

MAGNETOMETER (TOTAL FIELD) MEASUREMENTS FOR DETECTION OF BURIED METAL OBJECTS

INTRODUCTION

The magnetic method is a versatile, relatively inexpensive, geophysical exploration technique. Aeromagnetic surveys and deep water marine studies are commonly used as a reconnaissance tool for tracing large-scale geologic structure. Land and coastal water marine data are more useful in tracing smaller, more localized geologic structures, such as mineral and ore deposits. Land and marine surveys yield more detail and higher resolution, since the measurements are taken closer to the anomaly source. Land and shallow water magnetic data is commonly used to locate larger buried, man-made objects such as pipelines, barrels or other buried metal objects, and smaller objects such as involved in archaeological prospecting.

EARTH MAGNETISM

Magnetics is a "potential field" method. For a given magnetic field, the magnetic force in a given direction is equal to the derivative of the magnetic potential in that direction. The source of the earth's magnetic potential is its own magnetic field and the induction effect this field has on magnetic objects or bodies above and below the surface. The earth's field is a vector quantity having a unique magnitude and direction at every point on the earth's surface. This magnetic field is defined in three dimensions by angular quantities known as declination and inclination. Declination is defined as the angle between geographic north and magnetic north, and inclination is the angle between the direction of the earth's field and the horizontal [Figure 1]. The earth's magnetic field is measured in "gammas" [where 1 gamma = 10^{-5} Oersted]; the total field ranges from about 25,000 gammas near the equator to 70,000 gammas near the poles.

The earth's magnetic field is not completely stable. It undergoes long-term [secular] variations over centuries; small, daily [diurnal] variations [less than 1% of the total field magnitude]; and transient fluctuations called magnetic storms resulting from solar flare phenomena.

The earth's ambient magnetic field is modified locally by both naturally- occurring and man-made magnetic materials. Iron or steel objects act as "local" dipoles, which are generally oriented differently than the earth's external magnetic field.

The iron or steel objects represents a local perturbation in the main earth field. The net field in the vicinity of this perturbation is simply the vector sum of the induced and earth fields. Thus, the induced field is a function of the "susceptibility" of the material, or its ability to act like a magnet.

Remanent magnetization is produced in materials which have been heated above the Curie point allowing magnetic minerals in the material to become aligned with the earth's field before cooling. The remanent field direction is not always parallel to the earth's present field, and can often be completely reversed. The remanent field combines vectorially with the ambient and induced field components. The contribution of the remanent components must be considered in magnetic interpretations.

INSTRUMENTATION

At present, the most widely used magnetometer is the "proton precession" type. This device utilizes the precession of spinning protons of the hydrogen atoms in a sample of fluid [kerosene, alcohol, or water] to measure total magnetic field intensity.

Protons spinning in an atomic nucleus behave like magnetic dipoles, which are aligned [polarized] in a uniform magnetic field. The protons initially aligned themselves parallel to the earth's field. A second, much stronger magnetic field is produced approximately perpendicular to the earth's field by introducing currents through a coil of wire. The protons become temporarily aligned with this stronger secondary field. When this secondary field is removed, the protons tend to realign [precess] themselves parallel to the earth's field direction. The precessing protons will generate a small electric signal in the same coil used to polarize them with a frequency [about 2,000 Hz] proportional to the total magnetic field intensity but independent of the coil orientation. By measuring the signal frequency, the absolute value of the total earth field intensity can be obtained to a 1 gamma accuracy. The total magnetic field value measured by the proton precession magnetometer is the net vector sum of the ambient earth's field and any local induced and/or remanent perturbations.

A total field proton precession magnetometer can be made portable and does not require orientation or leveling. There are a few limitations associated with the precession system. The precession signal can be severely degraded in the presence of large field gradients [greater than 200 gammas per foot] near 60-cycle A/C power lines. Also, the interpretation of total field data is sometimes more complicated than vertical field data which, however, is more time consuming to take.

FIELD TECHNIQUES

The field operator must avoid or note any sources of high magnetic gradients and alternating currents, such as power lines, buildings, and any large iron or steel objects. Readings are taken at a predetermined interval which depends on the nature of the survey, the accuracy required, and the gradients encountered. Base station readings, if required, are usually made several times a day to check for diurnal variations and magnetic storms.

INTERPRETATION

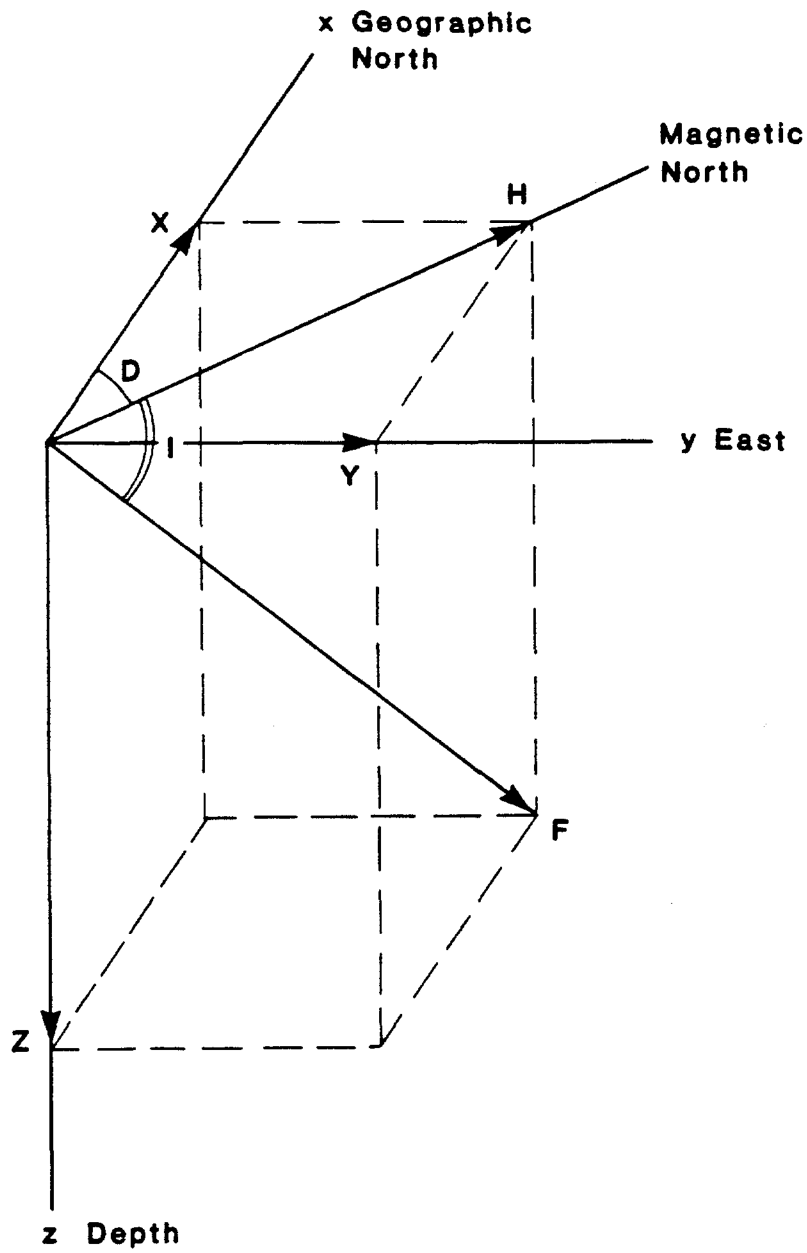
Lateral variations in susceptibility and/or remanent magnetization in crustal rocks give rise to localized anomalies in the measured total magnetic field intensity. Geologic structural features [faults, contacts, intrusions, etc.] and metal objects will cause magnetic anomalies, which can be interpreted to define the location of the causative source.

After diurnal effects and regional gradients have been removed, magnetic anomalies can be studied in detail with derivative operations and frequency filtering employed to define depth and shape.

Because it is a potential field method, there are a number of possible source configurations for any given magnetic anomaly. There is also an inherent complexity in magnetic dipole behavior. If the various magnetic field parameters [inclination, declination, and susceptibility] are well defined, and some reasonable assumptions can be made regarding the nature of the source, an accurate source model can generally be derived.

Magnetic anomalies can be analyzed both qualitatively and quantitatively. The physical dimensions of an anomaly [slope, wave-length, amplitude, etc.] often reveal enough to draw some general qualitative conclusions regarding the location and depth of the causative source.

Precise interpretation must be done quantitatively and requires prior knowledge of earth and remanent magnetic field parameters. Modeling can be performed by various approximation methods, whereby one reduces the source to a system of poles or dipoles, or assumes it to be one of several simple, geometric forms [vertical prism, horizontal slab, step, etc.]. The magnetic properties for this simplified model can be rather easily defined mathematically. Simple formulas can be derived which relate readily measurable anomaly parameters, such as slope, width, and amplitude ratios, to the general dimensions of the anomaly source, including depth to top, thickness, dip, and width normal to strike. Since these methods involve very limiting geometric assumptions, the results can be treated as good approximations only for very simplified sources.



I = Inclination

D = Declination

H = Horizontal Field Strength

F = Total Magnetic Force

ELEMENTS OF THE EARTH'S MAGNETIC FIELD

FIGURE 1

APPENDIX B

ELECTROMAGNETIC TERRAIN CONDUCTIVITY MEASUREMENTS

GENERAL CONSIDERATIONS

The electromagnetic terrain conductivity [EM] survey is a method of obtaining subsurface information through "remote" inductive electric measurements made at the surface of the earth. Although limited in application, the EM method has significant advantage in speed and definition for certain problems. The parameter measured with this technique is the apparent conductivity of the subsurface. The conductivity meter consists of receiver coil and a separate transmitter coil which induces an electrical source field [a circular eddy current loop] in the earth [Figure 1]. Each current loop generates a magnetic field proportional to the value of the current flowing within the loop. Part of the magnetic field from each current loop is intercepted by the receiver coil and converted to an output voltage which is linearly related to terrain conductivity. EM instrument readings are in millimhos per meter.

Geologic materials can be characterized by their electrical characteristics; lateral variations in conductivity values generally indicate a change in subsurface conditions. The relative conductivity of earth materials is particularly sensitive to water content and dissolved salts or ions. Accordingly, dry sands and gravels, and massive rock formations have low conductivity values; conversely, most clays and materials with a high ion content have high conductivity values.

FIELD PROCEDURE FOR DATA ACQUISITION

Weston Geophysical generally uses two common terrain conductivity meters: the Geonics EM-31 and the EM-34-3. The EM-31 has a fixed intercoil spacing of 3.7 meters and an effective depth of penetration of approximately 6 meters. The EM-34-3 has two coils which can be separated by 10, 20, or 40 meters and can be oriented in either the horizontal or vertical dipole modes. Intercoil separations increase the effective depth of investigation as shown below.

Intercoil Spacing [meters]	Depth of Investigation [meters]	
	Horizontal Dipoles	Vertical Dipoles
10	7.5	15
20	15	30
40	30	60

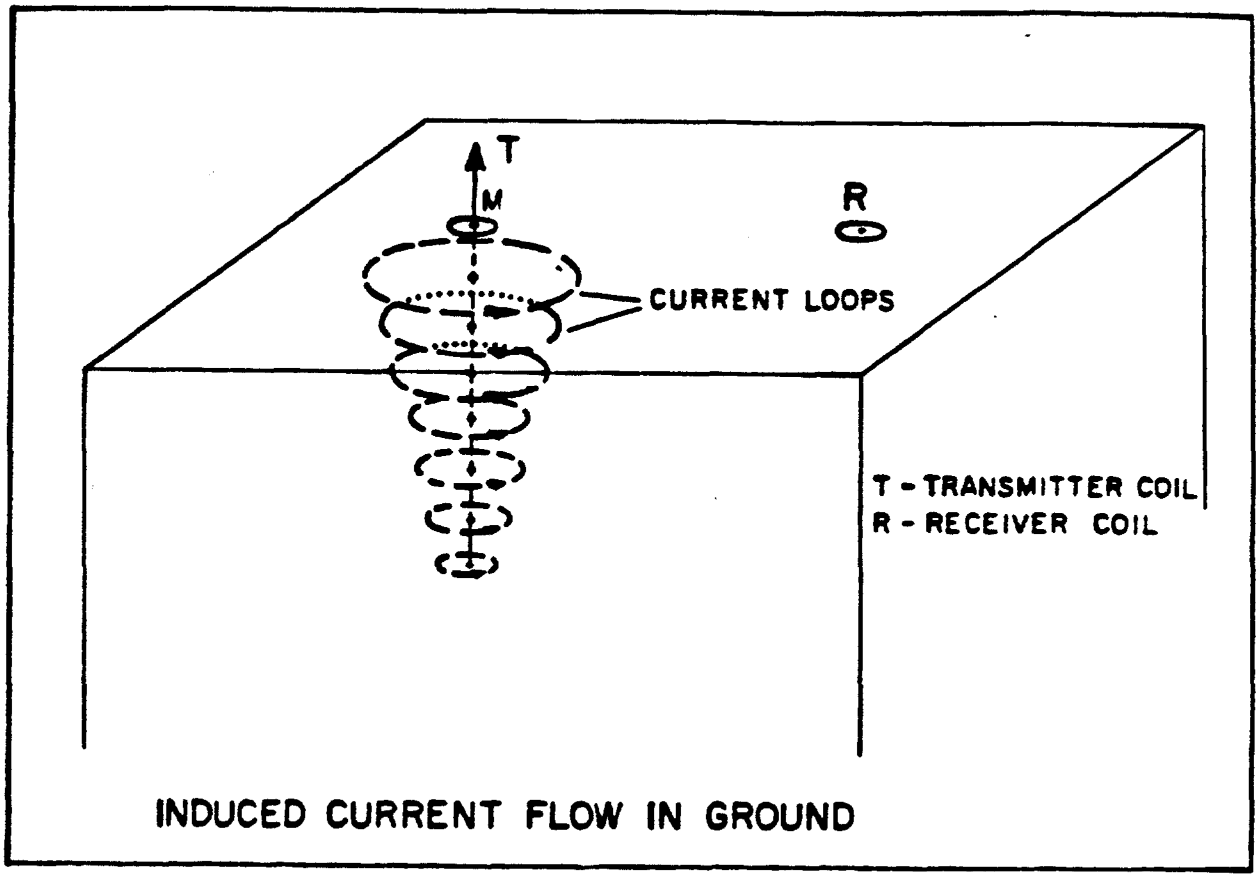
The coil orientation [horizontal or vertical] allows the EM-34-3 to respond to materials of different depths.

Conductivity measurements obtained with the EM-31 and/or the EM-34-3 can be obtained at any spacing along a survey line. EM-31 readings have the added flexibility of being recorded on a continuous chart recorder providing continuous data along a survey line.

DATA INTERPRETATION

EM data interpretation is generally subjective, that is measured EM values are contoured or profiled to identify high or low conductivity locations. Conductivity values obtained by an EM survey are relative values and depth estimates to conductive surface or bodies are best accomplished with an on-site calibration.

The EM-31 and EM-34-3 measure terrain conductivity in millimhos/meter. These values can be converted to resistivity [ohm/meters] for comparison with resistivity results by dividing the conductivity values into 1000.



Horizontal coplanar configuration (vertical dipole mode)

Figure 1

APPENDIX C

GROUND PENETRATING RADAR METHOD OF INVESTIGATION

GENERAL CONSIDERATIONS

Ground penetrating radar is an electromagnetic survey technique that reveals a graphic cross-sectional view of earth stratigraphy and point targets (i.e., drums, pipelines, utilities, boulders, etc.) below the ground surface. It is a reflection technique similar to the single-trace seismic reflection method commonly used in marine subbottom profiling. The two techniques differ in that the acoustic method uses audio frequency sound waves, while the radar method uses electromagnetic waves at frequencies of 80 to 1,000 megahertz (MHz).

In a radar system (Figure 1), high-frequency impulses of electromagnetic energy are generated by a transmitter in the antenna. Each impulse propagates downward through the ground surface and into the material below. At interfaces, part of the signal is reflected while part is transmitted still deeper to be reflected by other layers or isolated bodies. After transmitting the outgoing pulse, the antenna instantly switches from a transmitting mode to a receiving mode in order to detect the reflected signals.

During data acquisition, a graphic recorder provides an immediate view of the data. Radar impulses are transmitted in sync with a swept-stylus type graphic recorder. The graphic recorder stylus sweeps across the paper at a uniform speed and reflected signals above a user-selected threshold cause the paper to be darkened at points proportional to the amplitude of the reflection. Because the antenna is being pulled forward slowly, each pass of the stylus represents a slightly different antenna position. As the recorder paper advances, a continuous cross-section of reflections from subsurface stratigraphy and point targets is generated.

Data are recorded as a function of distance along the traverse versus time. Detected reflections are represented as the two way travel time to the reflector at a specific station location. Data enhancement is possible if the data are recorded on magnetic tape or diskette for later computer processing.

DATA INTERPRETATION

Figure 2 shows a GPR record of a buried river channel from a Weston Geophysical project in the northeastern United States. The dipping reflectors are indicative of the bedrock surface, while the nearly horizontal reflectors are from the overlying stratified fine sands.

Data is plotted as a function of antenna position versus time. Accurate determination of the depth to any layer requires calibration of the radar system. Calibration is performed by moving the antenna over a metal target with a known depth, such as a buried metal plate or pipe. Metallic objects typically are depicted by a characteristic hyperbolic anomaly. Figure 3 shows a GPR record over three buried fuel tanks. The time scale can then be converted to a depth scale by determining the location of the known reflector on the GPR record. If the depth to an observed reflector is not known, a borehole can be drilled or an excavation conducted to establish its depth. This is a more costly procedure, but it provides an exact depth calibration.

An approximation of the depth to a reflector can be made by estimating the velocity of the medium and by directly reading the travel times of the radar signals on the GPR recording. Velocity can be estimated by the equation:

$$V_m \approx C/\sqrt{K'}$$

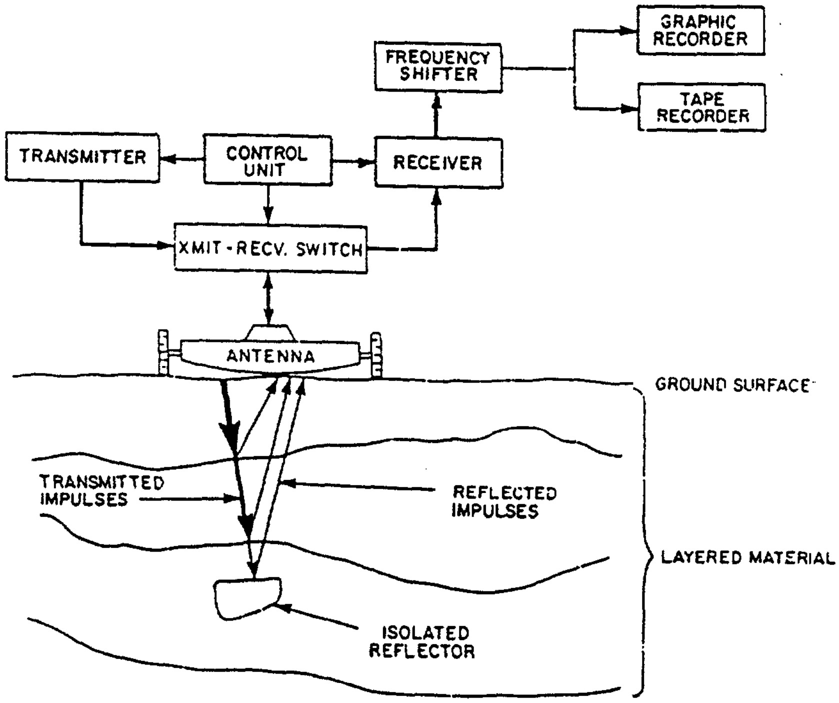
where

V_m is the velocity of the radar signals through the medium
C is the speed of light (2.998×10^8 m/s)

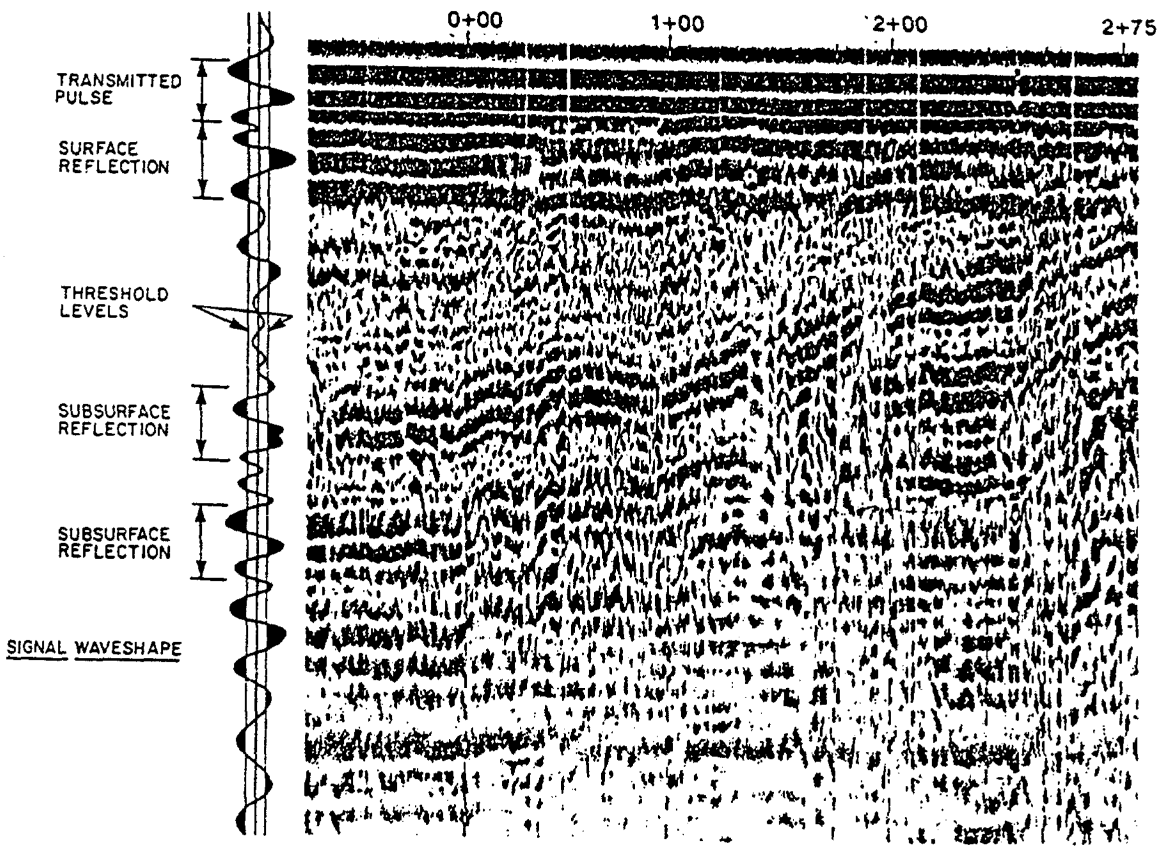
and K' is the dielectric constant (the real term at the relative dielectric permittivity). The values of the dielectric constant (electrical properties) for earth materials vary considerably and are affected by such conditions as porosity, degree of saturation, mineral composition, etc.

Depth of penetration in a given material is limited by attenuation of the signal. Attenuation is controlled by the amount of water and clay present in a material, the conductivity of the material and saturation fluids, and the degree of scattering of the electromagnetic signals. Penetration of up to 75 feet has been reported for water–saturated sands in a Massachusetts glacial delta. Signal penetration in saturated clays, however, is less than a few feet; signal penetration in sea water is less than one foot. It is important to note that in a layered material a single, highly reflective layer alone can limit penetration by preventing the propagation of energy past it. In this case, apparent loss of energy is caused by reflection rather than by signal attenuation.

Ground penetrating radar can be used to locate underground pipes and tanks, foundations, voids, sand, gravel, peat, and archeological artifacts. Layered structures in soils and hard rock can be charted accurately in continuous profiles. The effectiveness and speed with which modern systems can be used makes ground penetrating radar a logical choice where rapid and accurate shallow surveys are required.



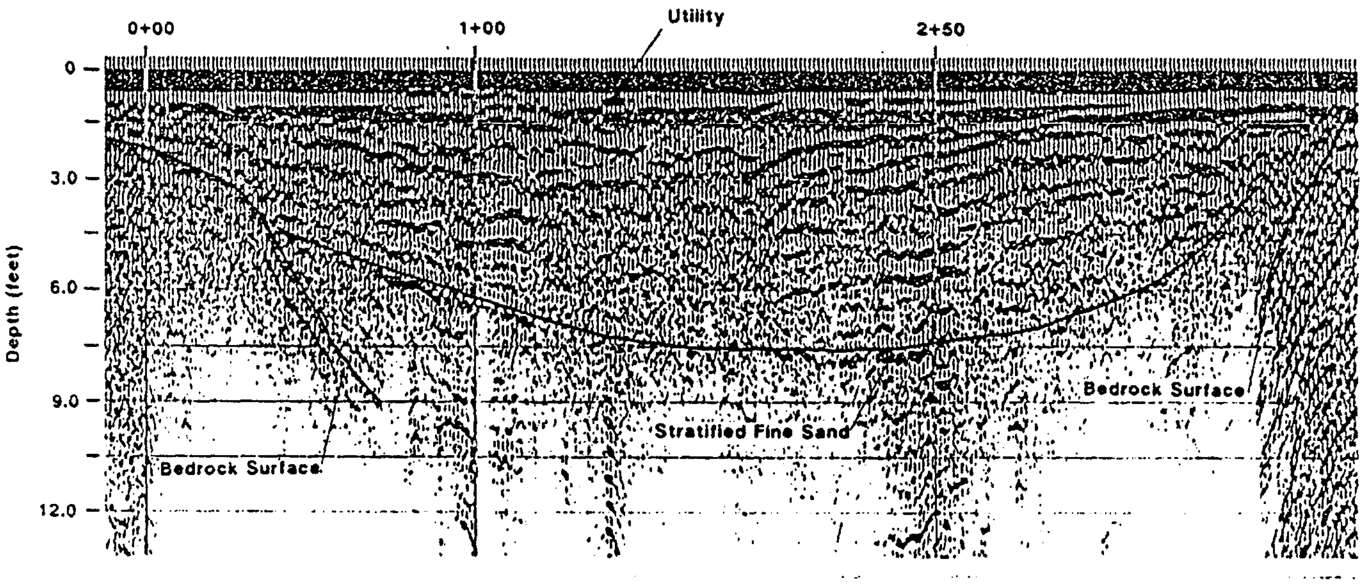
RADAR SYSTEM BLOCK DIAGRAM



TYPICAL RADAR RECORD

GROUND PENETRATING RADAR SET-UP

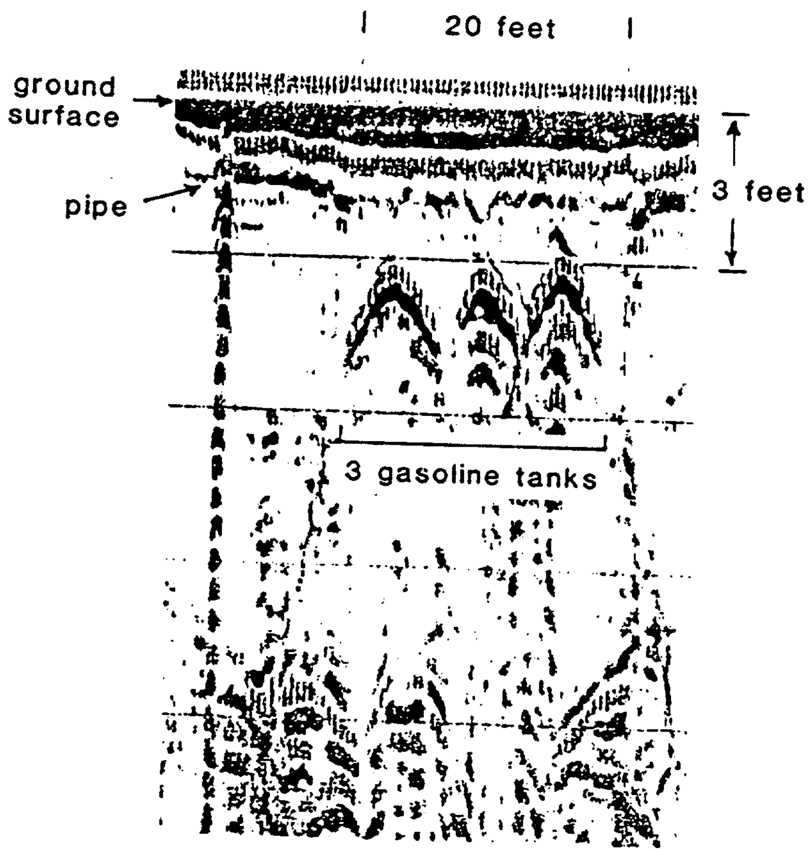
FIGURE 1



GROUND PENETRATING RADAR RECORD OF A BURIED RIVER CHANNEL

FIGURE 2

Weston Geophysical



GROUND PENETRATING RADAR RECORD OF BURIED FUEL TANKS

FIGURE 3

ATTACHMENT NO. 4

ROBERT BREEDING RESUME

Robert E. Breeding

EDUCATION

1980	M.S.	University of Southern Connecticut, Environmental Science
1973	B.S.	University of Connecticut, Natural Resources Conservation

SUMMARY OF EXPERIENCE

Mr. Breeding is a Senior Scientist with Atlantic Environmental Services, Inc. His academic background is in ecology and environmental impact assessment. Mr. Breeding has more than 15 years of experience in environmental science and hazardous materials management. His work has included:

- o Project Manager and Editor for preparation of RCRA Part B Permit Applications for hazardous waste treatment, storage, and disposal facilities including incineration facilities in Connecticut and Massachusetts.

- o Project Manager and Editor for preparation of hazardous waste treatment, storage, and disposal facility applications for "Certificate of Public Safety and Necessity" for submittal to the Connecticut Siting Council.

- o Principal QA/QC Coordinator for corporate QA/QC programs for RCRA/CERCLA projects and development of supporting library and recordkeeping system.

- o Designated Lead Project Engineer at a major electric utility for development of the following: a system-wide underground tank testing, removal, replacement, and retrofit program (addressing more than 400 tanks at over 50 corporate facilities); "Best Management Practices Plans for Chemical Storage, Handling and Disposal" for two major nuclear power facilities; and power plant hydrazine minimization and treatment studies.

- o Senior Project Scientist for numerous real estate environmental assessments including industrial, commercial and residential properties.

- o Project Scientist responsible for assessment and assurance corporate compliance with environmental statutes including regulations controlling PCBs, hazardous waste, effluent discharges and underground storage tanks.

- Project Scientist responsible for development and implementation of environmental audit and regulatory compliance assurance programs at corporate facilities.
- Project Scientist responsible for development preparedness plans for corporate facilities with small quantity generator status.
- Associate Scientist responsible for QA/QC in field collection, laboratory processing, and data analysis for a marine environmental research facility.

PROFESSIONAL CERTIFICATIONS AND REGISTRATIONS

Institute of Hazardous Materials Management, Certified Hazardous Materials Manager, Master Level.

National Registry of Environmental Professionals, Registered Environmental Professional (R.E.P.).

TABLE 1

**SUMMARY OF TEST BORINGS AND MONITOR WELLS INSTALLED
SEPTEMBER 1990**

PREVIOUS MONTH		SEPTEMBER 1990	
Area A Landfill/OBDA			
2L-M2-7D	2L-MW-14S (Boring only)	2L-MW-8D	
2L-MW-7S	2L-M2-14D	3L-MW-12D (OBDA)	
2L-MW-8S	2L-MW-17S	2L-TB-1	
2L-MW-9S	2L-MW-17D	2L-TB-3	
2L-MW-9D	2L-MW-18S	2L-TB-4	
2L-MW-13S	2L-MW-18D	2L-TB-5	6 Total
2L-MW-13D	3D-MW-12S (OBDA)		
	2L-TB-2		
	2L-TB-6		
	2L-TB-7		
Area A Wetland and Downstream			
2W-MW-1S (Boring only)	2D-MW-11S	2W-MW-1D	
2W-MW-2S (Boring only)	2W-TB-3	2W-MW-4S (Boring only)	
2W-MW-2D	2W-TB-8	2W-MW-4D	
2W-MW-3S		2W-MW-5	
2W-MW-3D		2W-MW-6D	
		2W-TB-1	
		2W-TB-2	
		2W-TB-4	
		2W-TB-6	
		2W-TB-7	
		2D-MW-10D	
		2D-MW-11D	
		2D-MW-15S (Boring only)	
		2D-MW-15D	
		2D-MW-16S	
		2D-MW-16D	16 Total
DRMO			
		TB-6	
		TB-7	
		MW-4	
		MW-5D	4 Total
			60 Complete to Date

TABLE 2

LABORATORY ANALYSIS
PERCENT COMPLETE BACKUP

	Total	Completed This Month
Site 1 (CBC)		
Soil/Sediment	7	0
Water	0	0
Site 4 (A86)		
Soil/Sediment	5	0
Water	0	0
Site 7 (Torpedo Shop)		
Soil/Sediment	10	10
Water	4	0
Site 8 (Goss Cove Landfill)		
Soil/Sediment	7	0
Water	5	0
Site 14 (OBDANE)		
Soil/Sediment	5	0
Water	0	0
Site 15 (Battery Acid)		
Soil/Sediment	7	0
Water	0	0
Site 18 (Gas Station)		
Soil/Sediment	5	0
Water	0	0
Area A Landfill		
Soil/Sediment	14	13
Water	14	0
Area A Wetland		
Soil/Sediment	54	0
Water	11	0
Area A Downstream		
Soil/Sediment	16	0
Water	20	0

Table 2 (continued)

Site 3 (OBDA)			
Soil/Sediment	11	0	
Water	2	0	
Site 6 (DRMO)			
Soil/Sediment	28	0	
Water	7	0	
Site 13 (Lower Base)			
Soil/Sediment	17	0	
Water	25	0	
	274	23	Percent Complete 8.4%